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Rapid Scientific Assessment of Mid-Scale Fire Regime Conditions in the Western U.S.

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Abstract

Altered fire regimes pose great threats to biodiversity. Fire managers recognize the need to reduce hazardous fuel loads, restore sustainable fire regimes and ecosystems, and decrease the threat of catastrophic wildfires to community values. The United States Department of Agriculture Forest Service recently provided national-level, coarse resolution data (1 km^2) on the degree and nature of departure of current vegetation and fuels from historic conditions. These coarse-scale fire regime condition class (FRCC) data represent a significant leap forward in the integration and mapping of biophysical, vegetation, and fuel characterization data for the purposes of gaining an ecologically-based perspective on national priorities for resource allocation for fire regime restoration, fuels treatment, and biodiversity conservation. Using this data, The Nature Conservancy (TNC) found that at least 43% of priority conservation area identified to-date in the US is moderately to severely at risk of significant degradation due to fire exclusion, the threat of unnaturally severe wildfires, introduction of exotics, or other past management activities. Fire exclusion was cited as a major threat in 43% of TNC conservation area plans and human-induced wildfire was cited as a threat in an additional 13% (unpubl. data). Such assessments are key to determining priorities for fire regime restoration and biodiversity conservation. However, the current coarse scale data has been misused for region- and project-level prioritization and planning. Currently available FRCC data only addresses prioritization nationally between larger regions and groups of states and not projects. Finer scale FRCC data is being developed through the LANDFIRE project using remote sensing and gradient modeling, but it is only in a prototype stage that will not lead to completion of the contiguous lower 48 states until 2008-2010. Using examples from a pilot assessment conducted for northern New Mexico (U.S.), we describe a novel approach for rapidly developing mid-scale spatial fire regime condition class data at scales appropriate for multi-area planning, assessment of potential long-term effects of alternative conservation strategies, prioritization of projects, development of fire management plans, and revision and amendment of agency forest and resource land management plans. The process uses existing spatial and remotely sensed data and quantitative state-transition models to provide fire regime condition class (FRCC) maps by potential vegetation type. Immediate availability of interim continuous spatial FRCC and associated data will accelerate coordination of the tasks of biodiversity restoration and fire hazard reduction across multi-ownership landscapes. Consistent, science-based measures of opportunities and risks across all land ownerships are a prerequisite for successful collaborative, multi-partner watershed-scale fire planning.

The Need for a Rapid Mid-scale Spatial Assessment of Fire Regime Conditions
Altered fire regimes pose great threats to biodiversity, ecosystem sustainability, and public and firefighter safety. Over ninety years of fire exclusion (Pyne 1982), domestic livestock grazing, logging, and widespread exotic species invasions throughout the U.S. have altered fire regimes and vegetation composition and structure (Savage and Swetnam 1990; Barrett et al. 1991; Brown et al. 1994; Quigley and Arbelbide 1997; Kaufmann et al. 1998). About 53% of all forests and rangelands in the U.S. have moderately to substantially altered fire regimes (Schmidt et al. 2002), and the number, size, and intensity of wildfires have changed from historical conditions (Kaufmann et al. 1998; U.S. GAO 1999; Swetnam and Baisan 2003). The Nature Conservancy (TNC) found that at least 43% of priority conservation area identified to-date in the US is moderately to severely at risk of significant degradation due to fire exclusion or the threat of unnaturally severe wildfires (unpubl. 2000 data). Across all lands more than 6.9 million acres burned during 2002, much more than the previous record-setting 2000 fire season, and more than one and a half times the acreage of the 10-year average. These large fires of 2002 not only wreaked havoc on ecosystem health and endangered firefighter safety, but also cost millions of dollars to control. More than $2.2 billion in federal funding was provided in 2002 for fire prevention, suppression and restoration (NIFC 2002). Although this figure represents a considerable increase, it is not nearly enough to treat all the lands where altered fire regimes pose a threat. As a result, U.S. legislators, land management agencies and partners need to employ efficient, cost-effective, and scientifically credible methods to prioritize areas for restoration treatments.

The National Fire Plan, chartered in 2000, together with the 10-year Cohesive Implementation Strategy engages states and local communities in a coordinated effort, using a variety of fuel reduction treatments (USDA and DOI 2000; USDA 2001). In the short-term, the focus is on areas near communities and interface areas where hazardous fuel reduction will reduce fire risk and fire suppression costs into the future. However, there remains a need to develop sound tools to prioritize limited resources between landscapes within and across regions. To do so, managers and the public demand analyses of scientifically credible, ecologically-based information that cuts across jurisdictional boundaries to help make local decisions about fuel treatment and ecosystem restoration priorities. Similarly, upper level decision-makers require consistent, accurate, efficient, ecologically based and scientifically credible information at national scales to facilitate appropriation and distribution of fire regime restoration resources. At regional and continental scales, it is difficult to accurately and consistently quantify current fire regime conditions since fire regimes, succession, fuel accumulation, and the confounded effects of fire exclusion and climate change are highly variable (Despain and Romme 1989; Agee 1993; Swanson et al. 1993; Minnich and Chou 1997; White and Walker 1997; Swetnam and Betancourt 1998; Barton et al. 2001; Swetnam and Baisan 2003). However, each time an extreme fire year makes its mark across landscapes, ecosystems and human communities, there emerges a demand for data to respond to questions and support pressing multi-scale fire management and prioritization decisions. Scientists must find effective fire regime condition assessment approaches that balance the needs for scientific credibility, spatial continuity, and quick delivery with those of data availability and data analysis time constraints.

The USDA Forest Service recently provided national-level, coarse resolution data (1 km^2) on the degree and nature of departure of current vegetation and fuels from historical conditions (Schmidt et al. 2002). This coarse-scale fire regime condition class (FRCC) data represented a significant leap forward in the integration, classification and mapping of biophysical, vegetation, and fuel characteristic data for the purposes of gaining an ecologically-based

perspective on national priorities for resource allocation for fire regime restoration, fuels treatment, and biodiversity conservation. Fire regime condition class (FRCC), a categorical measure of departure from historical fire regimes, is an index used for allocation of fire funding and resources, prioritization of fuels and restoration treatments, and evaluation of the successes and failures of historical wildfire management activity. Fire regime and associated national FRCC mapping have provided key spatial data for development of the USDA Forest Service and USDI cohesive strategies for restoration of fire adapted ecosystems and for addressing the goals and objectives of the National Fire Plan (U.S.D.A Forest Service 2001). Such assessments provide core data used in determining priorities for fire regime restoration and biodiversity conservation, and the FRCC concept is readily being adopted by the US Congress and land management decision-makers as a useful metric to account for the success of hazardous fuels and ecosystem restoration projects nation-wide. However, the current coarse scale data has been misused for region- and project-level prioritization and planning. Currently available FRCC data only addresses prioritization between large regions and groups of states and not projects. New field FRCC procedures (Hann et al. 2003a) support project-by-project assessment of FRCC (e.g., for areas 100s to 1000s of acres in size), but does not provide the spatial data and models necessary for comprehensive assessments nationwide. Finer scale FRCC data is being developed through the LANDFIRE project (http://www.landfire.gov/) using remote sensing and gradient modeling, but it is currently in a prototype stage and is not yet charged with analysis of the contiguous lower 48 states. Rapid mid-scale FRCC Assessments (e.g., at $1km^2$ to $30m^2$ resolution) are needed to bridge the gap between the available but limited-use coarse data and the fine-scale data that will not be widely available for five to ten years.

In this paper, we describe a rapid mid-scale process that provides spatial fire regime condition class data at resolutions appropriate for multi-area planning, assessment of potential long-term effects of alternative conservation strategies, prioritization of projects, development of fire management plans, and revision and amendment of agency forest and resource land management plans. It uses existing spatial and remotely sensed data and quantitative state-transition models to provide fire regime condition class (FRCC) maps by potential vegetation type at $30m^2$ pixel resolution. These interim spatial FRCC and associated data will help planners coordinate the tasks of biodiversity conservation, ecosystem restoration, and fire hazard reduction across multi-ownership landscapes when combined with information on other prioritization and management criteria, such as housing density, sensitive species, fire occurrence, transportation networks, and management constraints.

Project Objectives
The Rapid FRCC Assessment process was developed to cooperatively develop data at appropriate scales to directly address key priorities for the USFS, DOI and TNC, including those for forest and rangeland health, the National Fire Plan, the Cohesive Implementation Strategy, and biodiversity conservation. Specifically, the rapid assessment FRCC process was designed to benefit partners with mutual needs to:

- Assess fuel and vegetation-fuel conditions across public and private lands.
- Prioritize hazardous fuels reduction across public and private lands where the negative impacts of wildland fire to communities, ecosystems and biodiversity health are greatest.
- Provide a framework for development of biodiversity conservation strategies.
- Restore healthy, diverse, and resilient ecological systems to minimize uncharacteristically severe fires on a priority watershed basis through long-term restoration.
- Promote the development and use of the best available science.

- Monitor projects and facilitate multi-party adaptive implementation.

The prototype process was applied using available spatial data and published fire literature from northern New Mexico. In this region, public land managers, tribes, and The Nature Conservancy are working cooperatively to restore altered fire regimes, particularly in the Jemez Mountains, where in May of 2000 the Cerro Grande Fire caused 18,000 residents to be evacuated, cost about $1 billion (US), and burned 48,000 acres (Hill 2000).

Methods
The Rapid FRCC Assessment process is designed to use the most recent data available. The foundation for these methods is recent work in mapping environmental gradients (Keane et al. 2002), using reference ecological conditions in ecosystem management (Kaufmann et al. 1994; White and Walker 1997; Swetnam et al. 1999), and calculating departure of current from reference conditions (Hann et al. 2003b). Similar methods were described by Hann (Hann 2003) and McNicoll and Hann (McNicoll and Hann 2003) to classify FRCC at finer project scales.

Mapping objectives for accurate fine scale (40 hectares or less) pixel or polygon spatial typing require input layers of high spatial accuracy and substantial ground-truthing (Keane et al. 2002). In contrast, mapping objectives to achieve accurate composition of types within a much larger polygon can be achieved with relatively coarse spatial inputs (Hann et al. 1997). In addition, accurate relationships can be mapped using low resolution data through use of relative classifications (such as "low", "moderate", "high" risks or FRCC of 1 (low), 2 (moderate), 3 (high)) and non-species specific map legends (such as early, mid closed, mid open, late open, late closed forest stages) (Hann et al. 2003b). This project uses relative, non-species specific classifications to map polygons by FRCC.

A flowchart of project methodology is illustrated in Figure 1, and each step is briefly described below.

Rapid FRCC assessment steps
<u>1. Identify biophysical types and model reference conditions</u> – Potential natural vegetation types (PNVT) are one type of biophysical classification based on plant species that are indicators of the natural disturbance regime, site climate, and topo-edaphic relationships. Biophysical characteristics that to a large extent control fire regimes and the distribution of vegetation are reflected in the distribution of PNVTs. PNVTs are the foundation for stratification of reference and vegetation-fuel conditions, the development of reference models and calculation of departures between reference and current conditions. We used PNVTs classified by the Rocky Mountain Research Station Fire Modeling Institute (RMRS FMI) as the foundation for modeling reference conditions and mapping FRCC. Quantitative state-transition models for each PNVT occurring in the western U.S. were developed in conjunction with the Project Scale FRCC project (Hann et al. 2003a) using the Vegetation Dynamics Development Tool (VDDT) (Beukema and Kurz 2000). PNVTs included in the northern New Mexico prototype area include: pine forest, pine-Douglas-fir, southwest mixed conifer, spruce-fir, juniper-piñon, sagebrush, desert shrub, shinnery, plains grassland, desert grassland, and alpine meadows/barren. For each PNVT, literature reviews and expert input

Figure 1. Rapid Fire Regime Condition Class (FRCC) Assessment process.
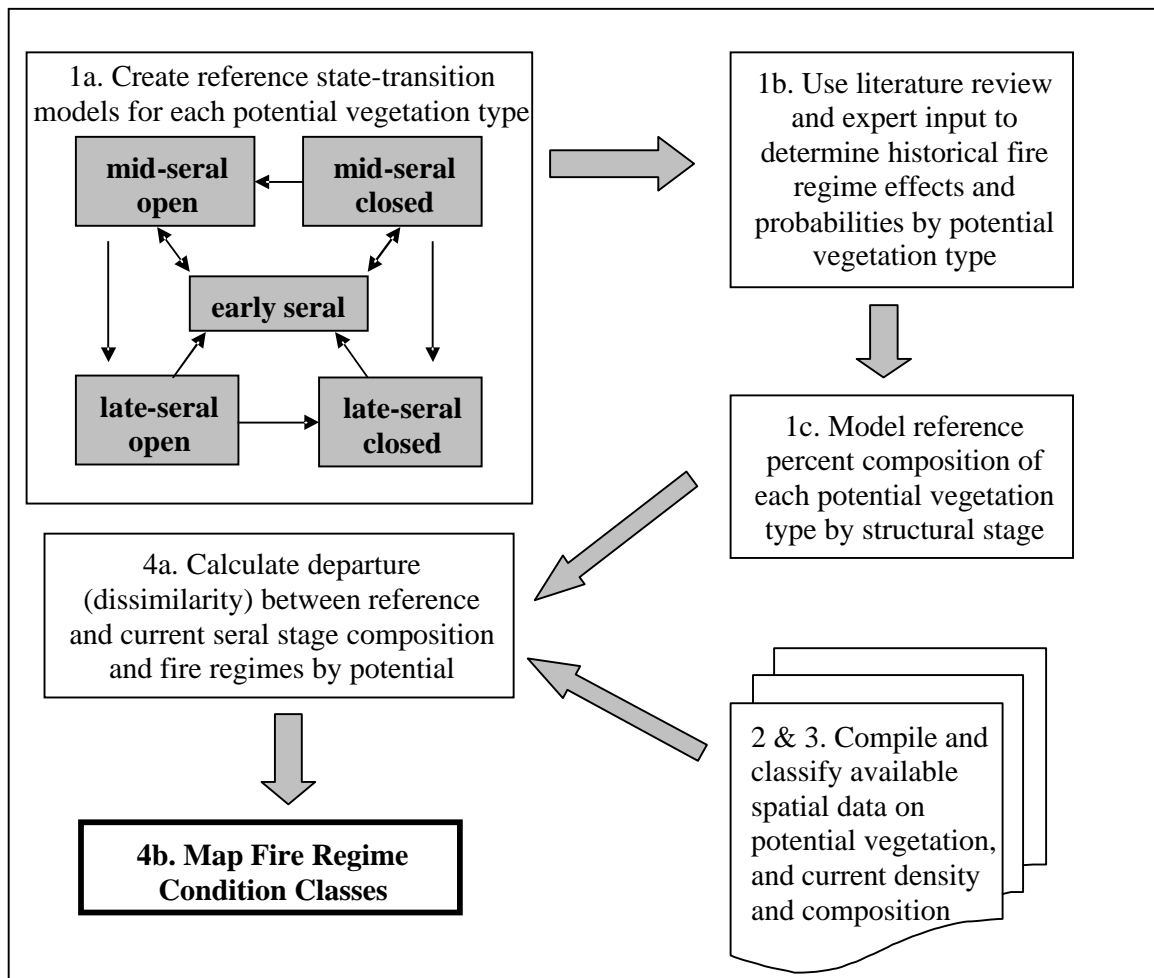
were used to estimate successional transition times, fire frequency and severity, and disturbance probabilities between a relatively simple set of structural stages expected to occur historically, and representing reference conditions. In most cases, structural stages were identified as early seral, mid-seral open, mid-seral closed, late-seral open, and late-seral closed, or a subset thereof. This simple classification was consistent with mid-scale spatial data available for structure and composition. VDDT models were then parameterized with reference successional and fire disturbance probabilities and run for 500-1000 years, or until PNVT structural stage composition stabilized. For example, Table 1 summarizes the parameters and reference composition for the ponderosa pine (*Pinus ponderosa*) PNVT used in the northern New Mexico prototype map (Stokes and Dieterich 1980; Baisan and Swetnam 1990; Kaufmann et al. 1998; Brown et al. 2000).

Table 1. Parameters and outcomes of VDDT reference model runs (10 Monte Carlo simulations over 500 years) for the ponderosa pine potential natural vegetation type for the northern New Mexico prototype of the Rapid FRCC Assessment process.

Fire Frequency and Severity Model Parameters

Fire Frequency-Severity	Interval (years)	Percent of Occurrences
Replacement Fire	100	5
Non-Replacement Fire	5	95
All Fire Frequency	5	100

Vegetation-Fuels Outcomes Relative to Current Conditions

Seral Stage	Density	Current % of PVT	Reference % Range of PVT
early	N/A	12	5-25
mid	closed	48	0-15
mid	open	20	5-22
late	open	2	30-65
late	closed	18	5-20

2. Map PNVTs using existing spatial data – The Rapid FRCC Assessment process requires the use of available spatial data on current land cover, PNVT and seral/structural stage to refine spatial data layers to mid-scale resolutions (e.g. 30m^2). Mapped PNVTs must coincide with models, fire regime characteristics and reference conditions developed in step 1. Lands converted to other uses, such as agriculture or urban development, can be classified as such, or a determination of the PNVT prior to conversion can be made. For the prototype area, we obtained current 30m^2 resolution current vegetation cover for New Mexico from the USGS Gap Analysis Program (GAP) (GAP 2002), and USGS Land Use/Land Cover data (developed from Landsat TM imagery, stratifying the landscape into "forest", "shrub", "water", and "other" categories), and cross-walked them with 1km^2 resolution PNVT data from the RMRS FMI. Classification of GAP and Land Use/Land Cover types by PNVTs allowed for refinement and cross-checking of PNVT data to 30m^2 resolution. Adjacency rules were used to assign anomalous pixels to PNVTs (e.g., pixels classified as "shrub" using USGS land cover and classified as a forest GAP type were assigned a PNVT through logical majority adjacency rules). The resulting PNVT layer remains to be peer-reviewed and validated in the field.

3. Classify and map seral/structural stages and uncharacteristic types – Landsat Thematic Mapper (TM) satellite imagery can be processed at 30m spatial resolution to develop a preliminary seral/structural stage map for vegetation-fuel in the assessment area. Seral/structural stages must coincide with classes used to model reference conditions in step 1. For fire regime condition classification purposes, grasslands and shrublands are generally classified based on the degree of shrub or tree encroachment. Classification of vegetation structure involves utilizing thematic stratification, unsupervised classification techniques, spatial modeling, and manual editing. Any existing GIS data pertaining to current seral stage, size class, structure, or any other pertinent vegetation characterization is evaluated and utilized to map structure where appropriate. For the remainder of the assessment area where existing GIS data is unavailable, an unsupervised classification of the Landsat TM imagery results in spectral classes that can be evaluated using aerial imagery, field-based plot data, or any other available ancillary data to determine the relationship between the spectral reflectance characteristics from the TM imagery and current structure/seral stages. Spectral

classes are then labeled as "early", "mid", or "late" seral stage. If available, other ancillary GIS data can be used to refine the resulting classification through spatial modeling. These models may include the use of elevation/aspect zones and current vegetation-fuel types to further stratify the spectral classes for more accurate labeling of structure. Also, for areas exhibiting spectral anomalies or known errors that can not be efficiently and effectively corrected through further automated image processing techniques, manual editing can enhance the thematic accuracy of the final structure classification. For the northern New Mexico prototype, we used existing USGS Land Use/Land Cover classification data to stratify the landscape into "forest", "shrub", "water", and "other" categories. An unsupervised classification of the Landsat TM imagery resulted in spectral classes that that were labeled as a "early", "mid", or "late" seral stage based on texture and information on land use history, such as the known year of large fires and expected structural classes at the time of the imagery. Young stands of regenerating trees or stands recently impacted by fire or mechanical manipulation present a unique spectral characteristic not often confused with more mature mid- and late-seral stage forests. Similarly, much older, mature forest with typically multi-storied structure and the presence of large trees also possess unique spectral reflective properties that distinguish them from younger forests. Uncharacteristic types, such as areas converted to invasive species that represent conditions not found in reference models, should also be identified and classified as "uncharacteristic". Future work will use existing ancillary GIS data sets to refine the classification of structure and uncharacteristic communities.

4. Calculate and map departure in vegetation/fuels and fire frequency/severity – The departure in vegetation/fuels and fire frequency/severity is calculated by comparing reference seral/structural stage compositions and fire frequency/severity by PNVT to current conditions. The detailed methodology used will not be described here, but is described by Hann et al. (2003a), and can be applied at any spatial scale. Combined vegetation and fire regime departures (dissimilarity) ranging from 0-33% are classified as "intact" or unaltered (FRCC 1). Departures ranging from 34-66% and 67-100% are classified as "moderate" (FRCC 2) or "high" (FRCC 3) departure, respectively. Areas mapped as "uncharacteristic" (e.g., areas dominated by exotic species) contribute in their entirety to dissimilarity between current and reference vegetation/fuel conditions. A summarized example of the calculation of departure in vegetation/fuels and fire frequency/severity for the ponderosa pine PNVT for the northern New Mexico prototype area is provided in Table 2. FRCC can then be mapped by PNVT to provide mid-scale information on conditions regionally.

Table 2. Summarized calculation of departure in vegetation/fuels and fire frequency/severity for the ponderosa pine PNVT for the northern New Mexico prototype area[1]

% of total PNVT area	early seral	mid-seral closed	mid-seral open	late-seral open	late-seral closed
Reference vegetation conditions (modeled)	5	5	15	65	10
Current conditions	12	48	20	2	18
% Similarity	5	5	15	2	10
Total % similarity = 37%; Dissimilarity = (1-37) = 63%				**FRCC (veg-fuels) = 2**	
Fire regime		Historical	Current	% Departure	
Fire frequency (MFI, years)		2-15	60-80	86	
% of burned area stand replacement		5-20	50-70	78	
				FRCC (frequency/severity) = 3	

Integrate other criteria – Other criteria, such as housing density, community proximity to natural areas, sensitive species, biodiversity value, risk of erosion or mass wasting, natural or human-caused fire occurrence, degree of landscape fragmentation, or road density may be used in conjunction with FRCC to develop priorities for management. Future development of the NM prototype will incorporate criteria important for regional and national project prioritization and planning, as determined by decision-makers at multiple scales.

Discussion and Conclusions
This Rapid FRCC Assessment process can provide critical ecological data for use in prioritization of fire use, fuel restoration and maintenance projects, development of multi-agency fire management plans, development of conservation area strategies, tracking success of restoration strategies, and revision and amendment of forest and resource land management plans. Specifically, this assessment process can:

- Provide a mid-scale, intermediate intensity assessment of fire regime conditions
- Provide interim data that can be used for national or regional prioritization and planning
- Provide input to fine scale, high accuracy, longer-term fire regime assessment projects
- Integrate existing ecological spatial data, and expert input across all ownerships
- Integrate with project scale fire regime condition assessment efforts

The development of the Rapid FRCC Assessment process and NM prototype took approximately 6 months and could easily be applied to other geographic areas. The greatest challenges for future application will be development of reference conditions, especially for ecosystems where little is known of natural fire regimes or vegetation mosaics. Great care needs to be taken in developing and utilizing reference conditions. Natural (historical) variability is a complex result of natural and human-induced change (Swanson et al. 1993; Kaufmann et al. 1994; White and Walker 1997; Swetnam et al. 1999). Reference conditions are extremely useful as indicators of ecosystem function and sustainability, but do not necessarily represent desired future conditions, or sustainable conditions under current climate, land use or managerial constraints.

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[1] See Hann et al. (2003a) for methods to calculate departure in vegetation -fuels and fire frequency-severity.

Certainly, as in any mapping effort using remotely sensed data, some errors will result in less than perfect classification results. It is anticipated that the greatest errors occurring from this type of analysis will be errors of omission from the late seral stage class in low density forest stands of 40% canopy cover or less. In these circumstances, reflectance from the existing forest canopy is often overwhelmed by other lower stature ground cover or the sparsely vegetated ground itself. Coupled with a forest density classification, current vegetation data, potential natural vegetation regimes, and empirically-derived fire regime dynamics models, the forest structure classification will facilitate the broad assessment of fire regime conditions. The nature of Rapid FRCC Assessments represents a trade-off between using the best available consistent data under short-time frames (e.g., 1 year or less) and using highly accurate data not currently available at large spatial scales. This trade-off necessitates the use of peer review, and model and field validation to the extent possible to ensure that data are as robust as possible. Through time, each of the assessment steps can be adjusted to enhance logic and potential accuracy based on review. Overall, this methodology will provide a reliable, consistent characterization of FRCC across regions or states in a relatively short period of time. Errors will be consistent and often quantifiable with moderate analysis of results, and this process will result in a consistent, effective, and efficient representation of FRCC.

Acknowledgements

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